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## THE BEARING VALUE OF ROLLERS

BY

WILBUR M. WILSON

RESEARCH PROFESSOR OF STRUCTURAL ENGINEERING



BULLETIN No. 263

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## CONTENTS

	PAGE
I. INTRODUCTION . . . . .	5
1. Object and Scope of Investigation . . . . .	5
2. Acknowledgments . . . . .	5
II. RELATION BETWEEN DIAMETER AND BEARING CAPACITY OF ROLLERS. . . . .	6
3. Rolling Tests by Brown and Hartmann . . . . .	6
4. Rolling Tests by Holt. . . . .	18
5. Static Tests by Brown and Hartmann . . . . .	21
6. Static Tests by Hedefine . . . . .	24
III. RELATION BETWEEN STRENGTH OF MATERIAL AND BEARING VALUE OF ROLLERS . . . . .	25
7. Static Tests by Hedefine . . . . .	25
8. Static Tests by Brown and Hartmann . . . . .	30
IV. SUMMARY OF RESULTS . . . . .	31
9. Summary of Results . . . . .	31

## LIST OF FIGURES

NO.	PAGE
1. Apparatus for Rolling Tests as Used by Brown and Hartmann . . . . .	6
2. Rollers and Bases Showing Location of Gage Lines Where Measurements Were Taken . . . . .	7
3. Relation Between Load and Spread in 1000 Strokes . . . . .	9
4. Relation Between Diameter and Bearing Value of Rollers . . . . .	12
5. Effect of Number of Strokes upon Spread . . . . .	13
6. Relation Between Load and Rolling Friction . . . . .	15
7. Effect of Number of Strokes on Friction . . . . .	16
8. Apparatus for Rolling Tests as Used by Holt . . . . .	18
9. Relation Between Load and Set; Static Tests by Brown and Hartmann . .	21
10. Relation Between Diameter and Bearing Value; Static Tests. . . . .	22
11. Relation Between Diameter and Bearing Value; Static Tests by Brown and Hartmann . . . . .	23
12. Load-Deformation Curves; Static Tests by Hedefine . . . . .	24
13. Relation Between Strength of Material and Bearing Value of Roller . .	30
14. Comparison of Bearing Values of Bases under Medium and Hard Rollers	31

## LIST OF TABLES

NO.	PAGE
1. Chemical and Physical Properties of Specimens Used by Brown and Hartmann . . . . .	10
2. Bearing Value of Rollers, from Rolling Tests by Brown and Hartmann . .	11
3. Physical Properties of Material for Series H; Rolling Tests by Holt. . .	17
4. Bearing Value of Rollers, from Series H; Rolling Tests by Holt . . . .	19
5. Physical Properties of Specimens, Series D; Static Tests by Hedefine . .	26
6. Chemical Composition and Heat Treatment of Specimens; Static Tests by Hedefine . . . . .	28
7. Physical Properties of Specimens; Static Tests by Hedefine . . . . .	29



## THE BEARING VALUE OF ROLLERS

### I. INTRODUCTION

1. *Object and Scope of Investigation.*—The object of this investigation is to determine the load-carrying capacity of small rollers similar to those used as expansion rollers and rockers of girder and truss bridges. The investigation included both static and rolling tests. In the study of the relation between the diameter of the roller and its bearing capacity, tests were made on rollers varying in diameter from 2 in. to 120 in. In the study to determine the relation between the strength of the material and the bearing capacity, tests were made on rollers made of the following kinds of steel: a medium grade of carbon steel castings, structural steel of specifications S.A.E. 1020, 1035, and 1045, manganese steel castings, and high-carbon tool steel. Tests were made on rollers of these materials after they had been stress-relieved, and after they had been hardened by heat treatment.

A few tests were made to determine the rolling friction of small rollers.

2. *Acknowledgments.*—The investigation was made as a part of the work of the Engineering Experiment Station of the University of Illinois, of which DEAN A. C. WILLARD is the director, and of the Department of Civil Engineering, of which Prof. W. C. HUNTINGTON is the head.

The material contained in this bulletin has been taken from three theses which were written under the supervision of the author and which were submitted in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering in the Graduate School of the University of Illinois. The theses are:

"An Experimental Study of Cylinders Bearing on Plane Surfaces,"  
by WILL KENNETH BROWN and ERNEST CHRISTIAN HARTMANN,  
1927.

"An Experimental Study of the Load Carrying Capacity of Steel  
Rollers," by MARSHALL HOLT, 1929.

"An Experimental Study of the Bearing Value of Steel Rollers,"  
by ALFRED HEDEFINE, 1931.

The specimens were heat treated by Mr. E. T. LANHAM, Superintendent of the Forge Laboratory in the Department of Mechanical Engineering of the University of Illinois.

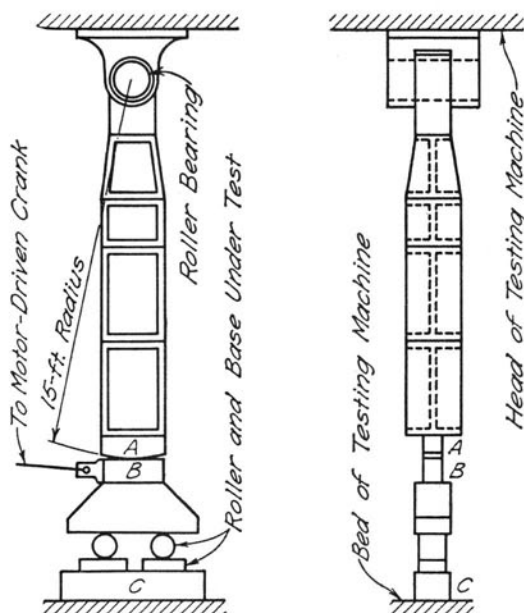


FIG. 1. APPARATUS FOR ROLLING TESTS AS USED BY BROWN AND HARTMANN

Mr. GEORGE E. JEWETT, Half-Time Graduate Research Assistant in Civil Engineering, made many of the tests reported in Mr. Hedefine's thesis.

## II. RELATION BETWEEN DIAMETER AND BEARING CAPACITY OF ROLLERS

3. *Rolling Tests by Brown and Hartmann.*—The rolling test consisted of rolling a steel roller 1000 strokes at each of a series of increasing loads until a load had been obtained which produced a permanent deformation in either the roller or the base on which it rolled. The apparatus used in these tests is shown in Fig. 1. The rollers and the small blocks on which they roll constitute the specimens. As a result of preliminary tests it was concluded that the spread of the roller and base, measured parallel to the axis of the roller at points near the surfaces in contact, was the most satisfactory phenomenon to use as a means of determining the minimum load producing permanent deformation in the roller or base. The elongation of the base, parallel to the plane of motion, was also measured, but this measurement was used only to insure that the base was so thick that spread would occur at a lower load than elongation.

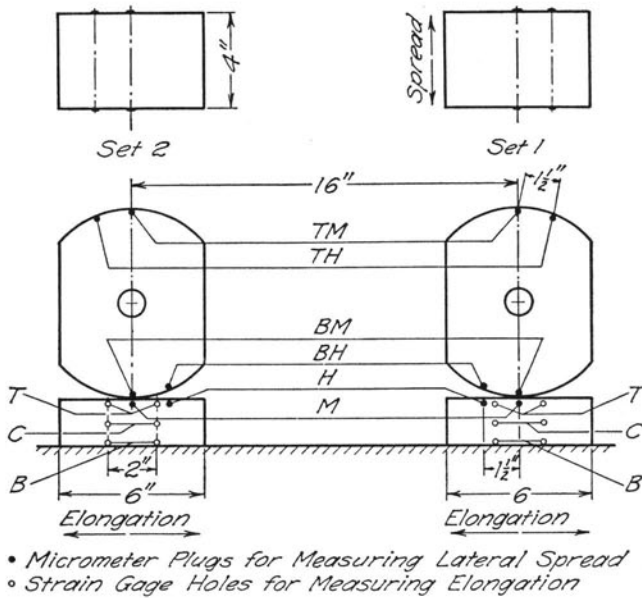


FIG. 2. ROLLERS AND BASES SHOWING LOCATION OF GAGE LINES WHERE MEASUREMENTS WERE TAKEN

The spread was measured with a micrometer caliper and the elongation with a 2-in. Berry strain gage. The micrometer readings were taken on steel pins projecting slightly from the ends of the roller and base. The locations of the micrometer plugs and strain-gage holes are shown in Fig. 2.

The load on the carriage is equally divided between the two rollers only when the carriage is in its mid-position. For other positions the load is unequally divided, and the larger portion goes to one roller when the carriage is in one extreme position and to the other when the carriage is in its other extreme position. The micrometer plugs are located so that there will be one pair at the line of contact when the carriage is in its mid-position and another at the line of contact when the carriage is at each of the extreme positions. The variation in the distribution of the load on the carriage between the rollers was taken into account in finding the minimum load on the roller that produced flow at each pair of micrometer plugs.

The relative positions of the rollers and bases are shown in Fig. 1. Before a test was started, a light load was put on the carriage and the positions of the specimens and apparatus were checked as follows:

- (1) for even pressure along the length of the rollers

- (2) for a constant total load throughout a stroke
- (3) for the position of the bases and rollers relative to the line of vertical pressure.

The first check was made by inserting a pair of 0.003-in. thickness gages on opposite sides of the line of contact between blocks *A* and *B* of Fig. 1, and noting whether or not they were parallel. If they were not parallel, indicating a lower pressure on one side than on the other, the load was removed and shims were placed under the low side of base *C* until, with reapplication of the load, the thickness gages were parallel.

The second check was made by reading the load on the testing machine when the carriage was in each extreme position. If the load dropped off at one end of a stroke, the block *B* in Fig. 1 was shimmed accordingly. This check was usually applied at each load of a test.

In the third check, the line of pressure was located by means of thickness gages used as in the first test. If the line of pressure was not properly located relative to the bases, the load was removed and the bases shifted to their proper position.

During a test the loaded rollers were rolled back and forth on the bases by means of a motor-driven crank. The crank made about 30 r.p.m. and had a radius of 4 in., giving the carriage a movement of approximately 4 in. each way from its mid-position.

The routine of a test as practised by Brown and Hartmann consisted of the following steps:

- (1) Zero strain readings with the micrometer and strain gage were taken at the points indicated in Fig. 2.
- (2) Specimens were placed in the testing machine and their positions under load checked as described in the preceding paragraphs.
- (3) The specimens were rolled 1000 strokes at a load which, as indicated by previous experience, would produce no permanent deformation.
- (4) The load was removed and a complete set of strain readings taken.
- (5) Operations 2, 3, and 4 were repeated in succession at increasingly higher loads until a considerable permanent deformation had been produced.

Figure 3 shows the relation between the load and the spread in 1000 strokes at each load for 10-in. rollers rolling on a base 2 in. thick. The flow increased very gradually as the load increased, and there is no point at which the specimen suddenly broke down. In the

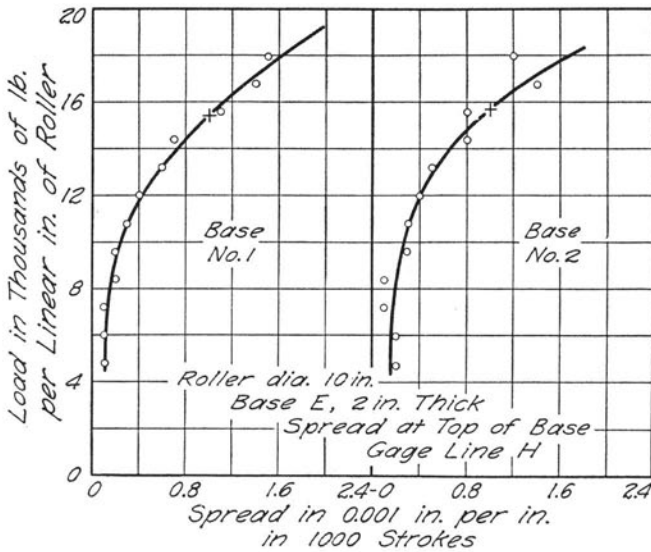


FIG. 3. RELATION BETWEEN LOAD AND SPREAD IN 1000 STROKES

absence of a "break" in the curve, the bearing value, the minimum load which produced an appreciable flow, has been arbitrarily selected as the load producing a unit flow in 1000 strokes of 0.001 in. per in. Observations showed that, in general, increasing the load above that producing a flow of 0.001 in. per in. in 1000 strokes caused a large increase in the flow. In other words, this criterion, though seemingly quite arbitrary, determines a load beyond which further increases in load cause a rapid increase in the flow. Moreover, the criterion is definite and free from any personal element.

The specimens used by Brown and Hartmann in the rolling tests to determine the relation between the diameter and the bearing value of rollers were all cut from a single medium-grade steel casting which, when planed on all surfaces, was 4 in. x 12 in. x 36 in. The block is specimen M of Table 1, which gives the chemical composition, heat treatment, and physical properties of the material.

All rollers were 4 in. long and were cut from two pieces each 4 in. x 6 in. x 12 in. cut from the parent casting. The specimens having a large diameter were segments of cylinders, as shown in Fig. 2. One segment was finished from each block by turning it in a lathe to a diameter of 12 in. Other rollers of the series were made from these two after they had been tested, by turning them down, successively, to diameters of  $11\frac{1}{2}$ , 10, 9, 8, 7,  $5\frac{1}{2}$ , and 4 inches. Each roller was

TABLE 1  
CHEMICAL AND PHYSICAL PROPERTIES OF SPECIMENS  
USED BY BROWN AND HARTMANN

Specimen	Material	Chemical Analysis					Heat Treatment	Physical Properties				
		C	P	S	Si	Mn		Ult. Tens. Strength lb. per sq. in.	Yield Point lb. per sq. in.	Elong. in 2 in. per cent	Red. of Area per cent	Brinell No.
Base	r	0.095	0.055	0.55	0.35	0.34	Held at 1650 deg. F. for one hour and then cooled in furnace.	54 000	26 900	37.0	63.5	108
	M	0.283	....	0.043	0.046	0.496	Held at 1500 deg. F. for three hours and then cooled in furnace.	.....	.....	....	....	131
	BB	0.30	....	....	0.38	0.62	Held at 1550 deg. F. for two hours and then cooled in furnace.	.....	.....	....	....	147
	t	0.34	0.045	0.068	0.37	0.801	Held at 1570 deg. F. for one hour and then cooled in furnace.	83 000	45 200	13.0	16.0	168
	v	0.68	0.029	0.044	0.64	0.824	Held at 1540 deg. F. for one hour and then cooled in furnace.	78 500	47 000	3.0	3.0	231
Cylinder	S	....	....	....	....	....	Commercially annealed	.....	.....	....	....	142
	M	0.283	....	0.043	0.046	0.496	Held at 1500 deg. F. for three hours and then cooled in furnace.	.....	.....	....	....	132
	H	....	....	....	....	....	Held at 1600 deg. F. for one hour and then dipped in water.	.....	.....	....	....	328

TABLE 2  
BEARING VALUE OF ROLLERS, FROM ROLLING TESTS BY BROWN AND HARTMANN  
Medium-grade steel castings

Diameter of Cylinder	Thickness of Base	Load Required to Produce Spread of 0.001 in. per in. in 1000 Strokes	
		Spread Measured at Top of Cylinder	Spread Measured at Bottom of Cylinder and Top of Base
		lb. per linear in. of roller	
in.	in.		
12	1	12 100	13 300
11.5	2	14 000	16 600
10	2	12 200	15 500
7	2	11 500	12 700
5.5	2	11 200	12 500
4	2	9 500	12 700

tested at each diameter before being turned to the next smaller diameter, tests being thus made on two specimens at each of the diameters listed.

The bases were cut from the same casting as the rollers. The bases for the 12-in. rollers were 4 in. wide measured parallel to the axis of the rollers, 6 in. long, and 1 in. deep. The bases for the other rollers were 2 in. deep but otherwise the same as the ones for the 12-in. rollers.

The relation between the load and the flow at the top of the base at gage point *H*, Fig. 2, for the 2-in. bases under the 10-in. rollers, is shown by Fig. 3. Similar diagrams were drawn for the flow at the tops of both bases and at gage lines *H* and *M* and the bearing value was determined from each of the four diagrams separately. Similarly, diagrams were drawn showing the spread at the bottoms of both rollers at gage lines *BH* and *BM*, and other diagrams were drawn showing the spread at the tops at gage lines *TH* and *TM*.

The bearing values, the minimum loads producing a flow of 0.001 in. per in. in 1000 strokes, are given in Table 2. The bearing values as determined from the spread at the top of the rollers are given in Column 3, and as determined from the spread at the bottom of the rollers and the top of the bases in Column 4. The large rollers had small blow holes at the top but none at the bottom. As the blocks were repeatedly finished to smaller diameters the blow holes disappeared, and there is no reason to believe that the physical properties of the steel were materially different at the top and bottom of the smaller rollers. The bottom of each roller was rolled upon a

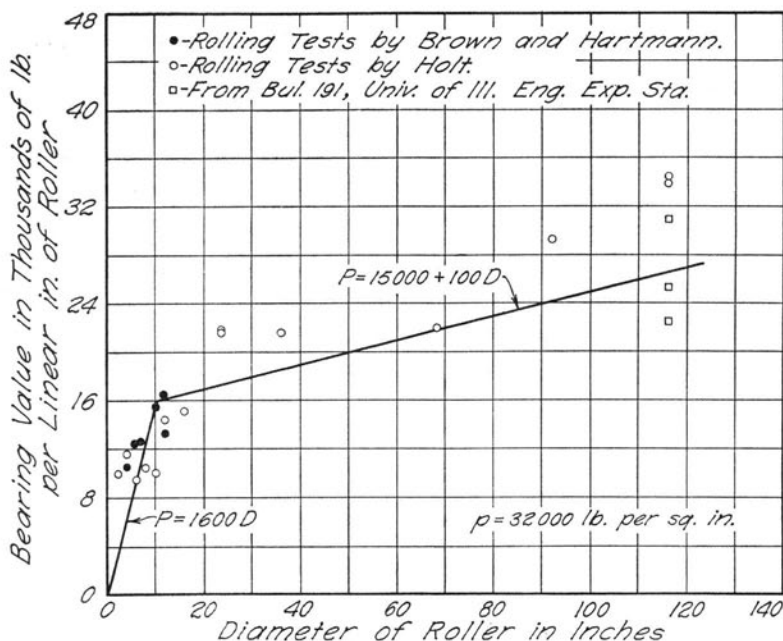


FIG. 4. RELATION BETWEEN DIAMETER AND BEARING VALUE OF ROLLERS

base of the same material as the roller, but the top was rolled under a very hard plate. It is believed that the top of the roller spread at a lower load than the bottom because of the hardness of the plate with which it was in contact. The bearing value of the roller on a base of equal strength is given by the spread at the bottom of the roller and at the top of the plate. The value of this load for each roller given in Table 2 is the average of the values obtained from eight curves, one from each of gage points *BH* and *BM* (Fig. 2) for each of two rollers, and one from each of gage points *H* and *M* for each of two bases. The relation between the diameter and the bearing value of the roller is shown graphically in Fig. 4.

The results of these tests are not as consistent as could be hoped for, but the difficulty encountered is apparent from the shape of the typical load-spread curve of Fig. 3. This curve intersects the vertical ordinate representing a spread of 0.001 in. per in. at a small angle, hence a small error in the measurement of the flow produces a large error in the determination of the load producing a flow of 0.001 in. per in. The bearing value increased with the diameter of the roller, but the range in diameter is not great enough to establish a definite



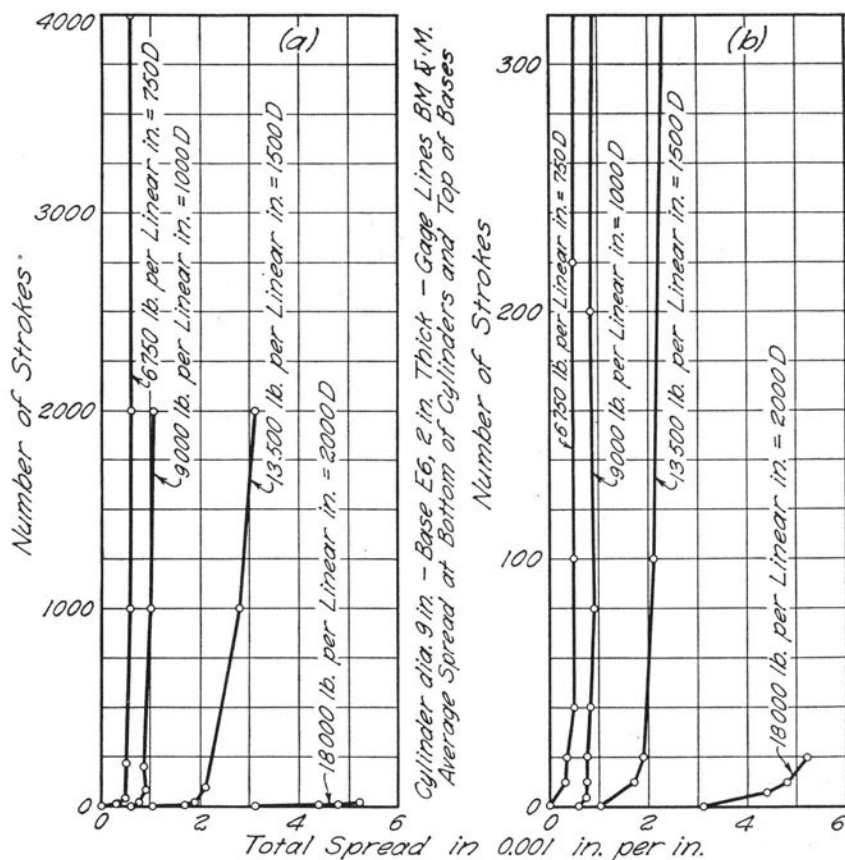


FIG. 5. EFFECT OF NUMBER OF STROKES UPON SPREAD

relation between the two variables. The strength of the small rollers is somewhat greater than expected, being approximately 1600  $D$  in lb. per linear in. for rollers up to 10 inches in diameter.

Tests were made on 9-in. rollers to determine the relation between the flow and the number of strokes at each load. The results of these tests are presented in Fig. 5. The flow is the average of the values at the bottom of the two rollers and at the top of the two bases, gage lines  $BM$  and  $M$ , Fig. 2. Figure 5a gives the flow up to 4000 strokes, and 5b the flow, to a larger scale, up to 300 strokes. These diagrams indicate that the rate of flow is much greater during the first few strokes at a given load than it is later. The flow under a load of 6750 lb. per linear in. was 0.0003 in. per in. during the first ten strokes, 0.0002 in. per in. during the next thirty strokes, and 0.0001 in. per in. during

the next 3960 strokes. A load of 9000 lb. per linear in. produced a flow of 0.0004 in. per in. in 1000 strokes. The same roller was rolled 2000 strokes at a load of 13 500 lb. per linear in. The elongation at this load was 0.0007 in. per in. during the first 10 strokes, and 0.0003 in. per in. during the last 1000 strokes. The rollers were rolled 20 strokes at 18 000 lb. per linear in., a load about 20 per cent greater than the "bearing value" of the roller. The rolling friction at this load was so great that the motor would not drive the crank and the machine was operated by hand. Because of this difficulty, rolling was discontinued at the end of 20 strokes. The decrease in the rate of flow as rolling continued is apparent, however, at this load even during the small number of strokes that the machine was operated. In view of the reduction in the rate of flow as rolling continues, the load that produces a flow of 0.001 in. per in. in 1000 strokes appears to be a very conservative value to use as the bearing value of a roller.

Observations were made to determine the horizontal force necessary to roll loaded rollers. These observations were made in connection with the tests to determine the relation between the diameter and the bearing capacity, which have just been described. In these tests, the crank driving the carriage was turned by hand and the connecting rod contained a calibrated spring whose extension and contraction indicated the thrust in the rod. This thrust was autographically recorded on a card mounted on a drum rotated by the movement of the carriage.

Figure 6 presents typical diagrams showing the relation between the load and the horizontal force necessary to roll the roller for rollers 4, 8, and 10 in. in diameter. For all tests the rate of increase of resistance to rolling increased gradually with the load on the rollers. Figure 7 shows the effect of continuous rolling at a given load upon the rolling friction at that load. At all loads the friction dropped off as the rolling continued, and the decrease was rapid during the first few strokes and became less rapid as rolling continued, until no further decrease was noted. In general, the friction at a given load was measured before making the test to determine the flow and the friction reported is the maximum that would be likely to occur.

The horizontal force,  $H$ , which was measured was the force necessary to move the carriage. This included the friction at the bottom and at the top of the roller, and also the friction between the blocks  $A$  and  $B$ , Fig. 1. The latter is very small, and the friction at the top of the rollers is probably less than that at the bottom since the plate at the top is harder than the one at the bottom. The sum of the fric-

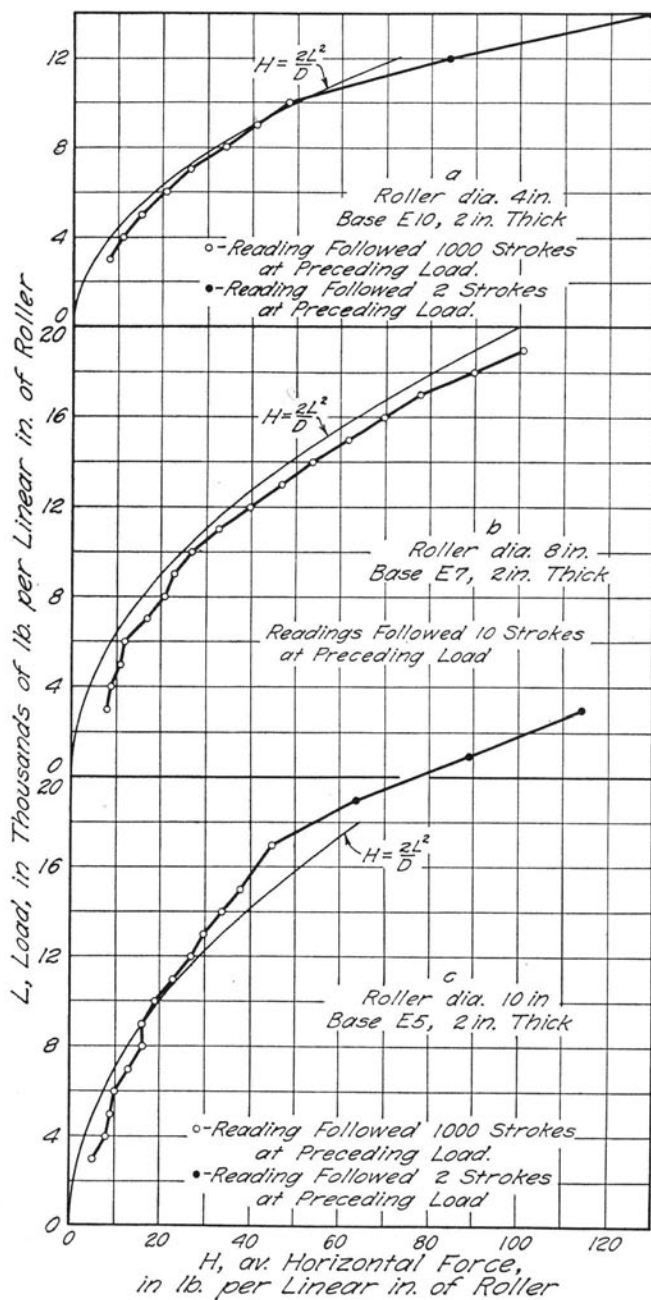


FIG. 6. RELATION BETWEEN LOAD AND ROLLING FRICTION

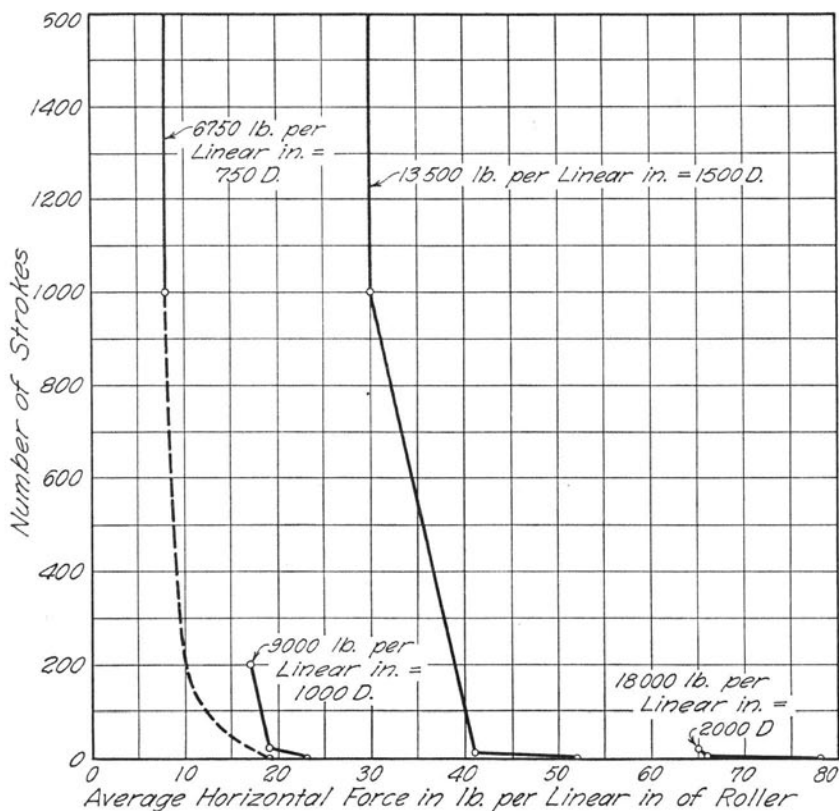


FIG. 7. EFFECT OF NUMBER OF STROKES ON FRICTION

tion between *A* and *B* and the friction at the top of the roller is probably approximately equal to the friction at the bottom of the roller where the roller and base are of the same material. The force *H* may, therefore, be considered as the force necessary to overcome two frictions for each roller, one at the top and the other at the bottom. Likewise the point of application of the force moves twice as far as the centers of the rollers. On this basis, the friction computed by the

formula  $H = \frac{2L^2}{D}$  agrees well with the experimental data for the range

in diameter covered by this series. In this formula, *H* is the horizontal force on the carriage in lb. per linear in. of roller, *L* is the load on the roller in thousands of lbs. per linear in. of roller, and *D* is the diameter of the roller in inches. The agreement between values computed by the preceding formula and the experimental data is shown in

TABLE 3  
PHYSICAL PROPERTIES OF MATERIAL FOR SERIES H; ROLLING TESTS BY HOLT

Specimen	Before Rolling					After Rolling				
	Ultimate Strength lb. per sq. in.	Yield Point lb. per sq. in.	Elongation in 2 in. per cent	Reduction of Area per cent	Brinell Number	Ultimate Strength lb. per sq. in.	Yield Point lb. per sq. in.	Elongation in 2 in. per cent	Reduction of Area per cent	Brinell Number
H1	64 410	30 960	31.00	40.72	128	65 820	37 440	24.50	30.31	147
H2	63 142	33 050	29.75	39.81	129	34 260	34 320	26.00	34.62	147
H3	.....	.....	.....	.....	141	.....	.....	.....	.....	159
H3A	64 500	31 880	27.25	36.39	128	65 030	34 640	27.87	38.76	151
H5	.....	.....	.....	.....	118	.....	.....	.....	.....	134
H5A	64 870	32 790	31.87	46.33	130	65 160	33 410	20.81	46.30	157
H7	.....	.....	.....	.....	128	63 600	32 890	26.00	29.38	165
H7A	64 630	32 060	30.75	38.12	132	44 730	31 680	5.37	19.69	185
H9	64 660	33 600	26.50	45.41	.....	.....	.....	.....	.....	.....
H10	63 950	30 800	28.25	28.97	130	64 710	35 340	22.50	26.82	139
H12	64 130	30 920	28.12	33.16	129	64 490	34 590	26.50	31.17	139
H13	64 210	30 760	27.19	38.84	125	64 180	33 160	27.12	40.76	136
H14	65 700	31 500	27.75	39.69	128	64 310	33 660	28.00	38.84	138

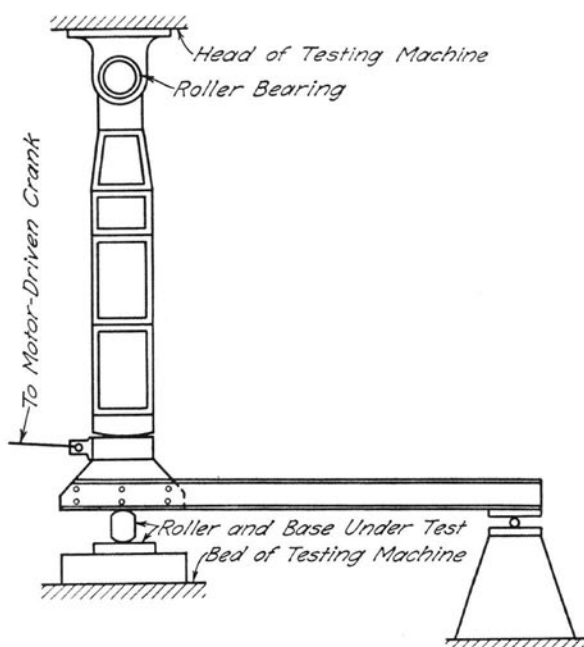


FIG. 8. APPARATUS FOR ROLLING TESTS AS USED BY HOLT

Fig. 6. The fact that the friction per unit load increases gradually with the load is consistent with the fact that the increase in flow per unit load increases with the load. Likewise, the fact that the friction at a given load decreases as rolling continues is consistent with the fact that the flow per stroke at a given load decreases as rolling continues.

4. *Rolling Tests by Holt.*—The rolling tests made by Holt to determine the relation between the diameter and the bearing capacity of rollers differ from those made by Brown and Hartmann in that they cover a larger range of diameter and the apparatus is so designed that the entire load weighed by the testing machine is carried by one roller.

The rollers varied in diameter from 2 in. to 116 in. All rollers were 4 in. long and all bases were 4 in. wide and 1.5 in. thick. All bases and all rollers less than 24 in. in diameter were cut from a single steel casting of medium grade 4 in. x 12 in. x 36 in. when machined on all surfaces. The rollers over 24 in. in diameter were cut from a similar casting. These castings, and the one from which the specimens used by Brown and Hartmann were cut, were all poured from the same heat

TABLE 4  
BEARING VALUE OF ROLLERS, FROM SERIES H; ROLLING TESTS BY HOLT  
Medium-grade steel castings

Specimen	Diameter of Roller	Load Required to Produce Flow of 0.001 in. per in. in 1000 Strokes		
		From Lateral Flow of Base	From Longitudinal Flow of Base	From Spread of Roller
	in.	lb. per linear in. of roller		
H7A	2	10 100	.....	.....
H7	4	11 700	.....	11 000
H9	6	9 500	.....	.....
H5A	8	10 600	.....	11 900
H3A	10	10 100	.....	11 400
H3	12	14 500	15 700	8 200
H5	16	15 200	13 300	14 900
H2	23 $\frac{1}{2}$	21 600	22 000	21 800
H1	23 $\frac{1}{2}$	21 800	21 100	22 500
H13	36	20 700	.....	.....
H12	68	22 100	30 000	.....
H11	92	29 300	30 000	.....
H10	116	34 500	33 300	.....
H14	116	34 000	33 300	.....

and received the same heat treatment. The physical properties of the material are given in Table 3.

The apparatus used by Holt is shown in Fig. 8. Before a test was made, the apparatus and specimens were checked for position by the methods used by Brown and Hartmann already described.

After preliminary studies of the phenomena of failure, Holt adopted the same criterion for the bearing value as had been used to interpret the tests by Brown and Hartmann. That is, the spread of the bottom of the roller and of the top of the base, due to rolling the specimen 1000 strokes at each of a number of increasing loads, was measured with a micrometer caliper. A diagram was then drawn showing the relation between the load and the lateral flow during 1000 strokes, separate diagrams being drawn for the bottom of the roller and the top of the base. The bearing value of the roller was arbitrarily selected as the minimum load at which the lateral flow in 1000 strokes was 0.001 in. per in. The longitudinal flow at the top of the base was measured with a 2-in. strain gage. The diagram showing the relation between the load and the longitudinal flow contained a sharp break for rollers having a diameter of 23.5 in. and greater, but the load corresponding to this break in the curve was usually equal to or greater than the bearing value determined from the lateral flow of the base. For the rollers less than 23.5 in. in diameter the diagrams showing the relation between the load and the longitudinal flow of the base did not have

a well-defined break. The bearing values for rollers of various sizes and as determined by the various methods are given in Table 4. The relation between the diameter and the bearing capacity as determined by the lateral flow of the base is shown in Fig. 4. The results obtained by Holt and those obtained by Brown and Hartmann are shown separately in this figure. The results of rolling tests of plates, taken from Bulletin 191, Engineering Experiment Station of the University of Illinois, are also included.

Tests of plates rolled under rollers varying in diameter from 116 in. to 476 in.\* indicated that the bearing value is given by the empirical equation  $P = \left[ \frac{p - 13\ 000}{23\ 000} \right] [18\ 000 + 120\ D]$ , in which  $P$  is the bearing value in lb. per linear in. of roller,  $p$  is the yield-point strength of the steel in tension in lb. per sq. in., and  $D$  is the diameter of the roller in inches. The steel used in the tests reported in Fig. 4 had a yield point of 32 000 lb. per sq. in. and, for this value of  $p$ , the preceding equation reduces to the form  $P = 15\ 000 + 100\ D$ . The full-line diagram of Fig. 4, whose equation is  $P = 15\ 000 + 100\ D$ , passes through the lower edge of the field representing the results of the tests by Brown and Hartmann and by Holt, for rollers larger than 10 in. in diameter. For smaller rollers, the results of the tests are well represented by the equation  $P = 1600\ D$ .

An interesting feature of the tests is the greater average vertical pressure over the area in contact, required to produce an appreciable flow, for small rollers than for large ones. From Hertz's analysis,† the average vertical pressure over the area in contact is  $p_a =$

$\frac{P}{0.0004\sqrt{PD}}$ . Substituting for  $P$  the bearing value as given by the equations in the preceding paragraphs,  $p_a$  for 9-, 25-, and 100-in. rollers has values of 100 000, 66 000, and 40 000 lb. per sq. in. respectively. The rollers for which this comparison is made were of steel having a yield point in tension of 32 000 lb. per sq. in. This same relation between the diameter and the average pressure at the critical load was noted in tests of large rollers.‡ Tests on the bearing value of knife edges§ indicated that, for tool steel knife edges bearing on bases of the same material, the average pressure over the area in contact corresponding to the minimum load producing a detectable set was greater than 500 000 lb. per sq. in.

\*Univ. of Ill. Eng. Exp. Sta. Bul. 191.

†Ibid., p. 45.

‡Univ. of Ill. Eng. Exp. Sta. Bul. 162, p. 59.

§Univ. of Ill. Eng. Exp. Sta. Bul. 242, p. 46.



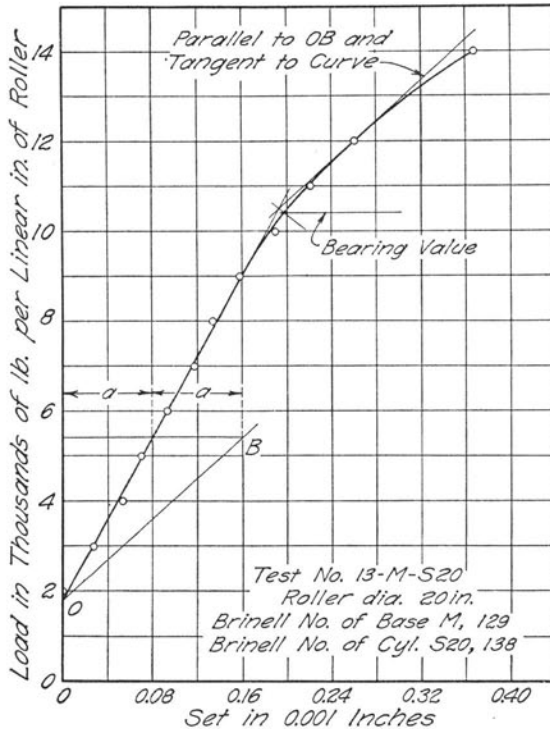


FIG. 9. RELATION BETWEEN LOAD AND SET; STATIC TESTS  
 BY BROWN AND HARTMANN

5. *Static Tests by Brown and Hartmann.*—Two series of static tests were made by Brown and Hartmann to determine the relation between the diameter and the bearing capacity of rollers. The length of the rollers and the width of the bases were 2 in. for all series. The rollers were medium-grade steel castings 5 in., 10 in., 15 in., and 20 in. in diameter. A third series of static tests, planned to show the relation between the hardness of the material and the bearing value of the roller, is described in Section 8.

The test consisted of determining the relation between the load and the vertical set in those portions of the specimens just above and just below the area in contact. The set was measured with an attached extensometer. The gage line, which was bisected by the surface in contact between the two specimens, was three-eighths of an inch long. Figure 9 shows a typical load-set diagram. This curve contains no break, and hence was hard to interpret. Brown and Hartmann used the construction shown in the figure to determine the bear-

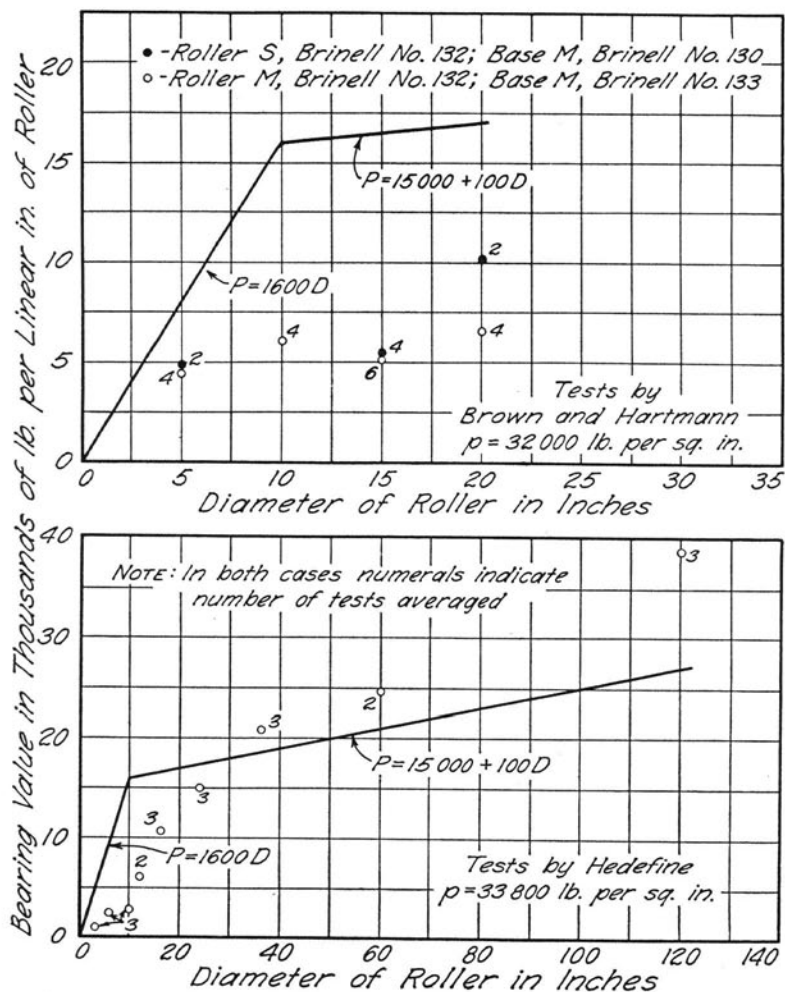


FIG. 10. RELATION BETWEEN DIAMETER AND BEARING VALUE; STATIC TESTS

ing value, the smallest load producing an appreciable set. The extensometer was very sensitive and a small set occurred at very small loads. The construction for locating the bearing value is based upon the fact that the load-set curve is a straight line near the origin but curves to the right as the load increases. The construction eliminates the personal element in the interpretation of the data, but it is more or less arbitrary, and a different construction would give a different interpretation to the same data. The construction does, however,

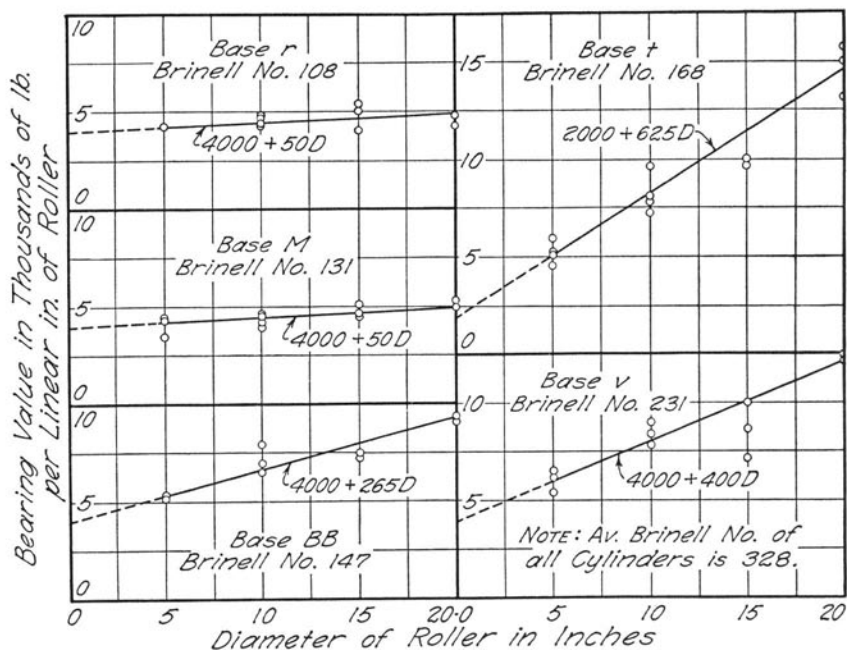


FIG. 11. RELATION BETWEEN DIAMETER AND BEARING VALUE; STATIC TESTS BY BROWN AND HARTMANN

give as the bearing value a load where the set begins to increase rapidly with additional increases in load.

The relation between the bearing value and the diameter is shown in Fig. 10. The roller *M* was made from the same casting as the base. The roller *S* was made from the same kind of material and had the same Brinell number as the base *M* but was poured from a different heat. The full-line diagram of Fig. 10 is the same as the full-line diagram of Fig. 4, and shows the relation between the diameter and the bearing capacity of rollers as determined by rolling tests. The small open circles of Fig. 10 represent the results of static tests on rollers and bases made of the same material, and this material was the same medium-grade carbon steel castings as used for the rollers and bases in the rolling tests reported in Fig. 4. Apparently for rollers 20 in. in diameter or less, the bearing value determined by the static tests, interpreted in the manner described, is considerably less than the bearing value as determined by the rolling tests.

In a second series of tests by Brown and Hartmann made to determine the relation between the diameter and the bearing capacity

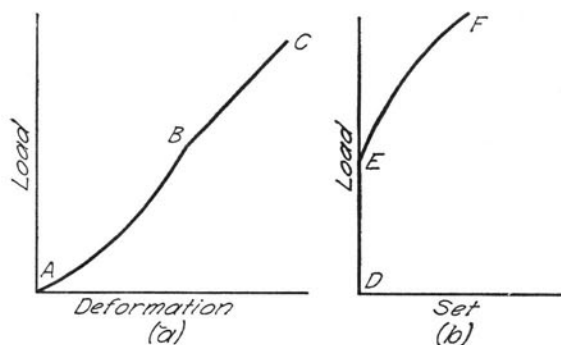


FIG. 12. LOAD-DEFORMATION CURVES; STATIC TESTS BY HEDEFINE

of rollers a hard roller was tested in contact with five bases varying in hardness from Brinell No. 108 to Brinell No. 231. Tests were made on rollers having diameters of 5 in., 10 in., 15 in., and 20 in. The rollers, designated by the letter *H*, were steel castings hardened by heat treatment as indicated in Table 1, and their Brinell No. was 328. The relation between the diameter and the bearing value of the rollers of this series when tested on the bases indicated is shown in Fig. 11. The increase in bearing capacity with diameter is very small for the soft bases, but is quite pronounced and definite for the hard bases.

6. *Static Tests by Hedefine.*—The bearing value of rollers was determined by Hedefine by two static tests that were conducted simultaneously. The vertical deformation of those portions of the material just above and just below the surfaces in contact were measured with a wedge extensometer.\* One reading was taken, with the specimen loaded, to determine the deformation; and another reading was taken at a small load (always the same load for a given test) following each of a number of successively increasing large loads, to determine the set. Ideal load-deformation and load-set curves for a roller and base made of a material having a well-defined yield point are shown in Fig. 12. The point *B*, the break in the curve of Fig. 12a, corresponds to the load at which some portion of the material is stressed to the yield point;† and the point *E*, the point at which the curve of Fig. 12b departs from the vertical, corresponds to the load at which some portion of the material is stressed to the elastic limit. But for both tests the actual curves differed from the ideal curves in such a way as to

\*This instrument is described in Bulletin 242, Univ. of Ill. Eng. Exp. Sta.

†Univ. of Ill. Eng. Exp. Sta. Bul. 162, p. 12.

make their interpretation difficult. The break in the curve corresponding to *B* of Fig. 12a was sometimes so indistinct that its exact location could not be determined. The method was used, however, for most of the tests. Because of the sensitiveness of the wedge extensometer, the curve corresponding to Fig. 12b invariably deviated from the vertical so near the origin that the point of deviation could not be considered as indicating the limit to the bearing capacity of the roller. Instead, Hedefine arbitrarily selected the load that produced a set of three divisions on the extensometer dial, 0.00006 in. set, as the bearing value. The values determined from the load-deformation and the load-set curves are both reported, but the former is believed to correspond more nearly to the bearing value of the roller.

In the first series of tests to determine the relation between the diameter and the bearing capacity of rollers, Hedefine used specimens made from medium-grade steel castings that had been poured from the same heat as the medium-grade steel castings used by Holt and by Brown and Hartmann. The bases were cut from one casting and the rollers from another. The physical properties of the material are given in Table 5. The length of the rollers and the width of the bases were 4 in. The thickness of the base was 1 in. for diameters of roller up to 12 in., 1.5 in. for diameters from 16 in. to 30 in., and 2 in. for diameters from 36 in. to 120 in.

The results of the tests are presented graphically in the lower portion of Fig. 10. The small circles represent the results of the static tests, and the numeral adjacent to a circle indicates the number of tests averaged. The full-line diagram is the empirical curve showing the relation between the diameter and the bearing value as determined by the rolling tests of Section 4. For rollers less than 20 in. in diameter the static test used by Hedefine, as well as the one used by Brown and Hartmann, gave values for the bearing value much less than the values determined by the rolling tests.

### III. RELATION BETWEEN STRENGTH OF MATERIAL AND BEARING VALUE OF ROLLERS

7. *Static Tests by Hedefine.*—A number of series of static tests were made by Hedefine to determine the effect of the strength of the material, as controlled by composition and heat treatment, upon the bearing value of rollers on plane bases. For all series the length of the roller and the width of the base were 4 in. for all specimens and the roller and base that were tested together were of the same kind

TABLE 5  
PHYSICAL PROPERTIES OF SPECIMENS, SERIES D; STATIC TESTS BY HEDEFINE

Specimen		Yield Point Strength lb. per sq. in.	Ultimate Strength lb. per sq. in.	Elongation in 2 in. per cent	Reduction of Area per cent	Brinell Number	Number of Tests Averaged
Diameter in.	Location						
120	Cylinder Base	32 960 34 290	61 750 61 360	21.4 16.1	27.5 22.4	121 131	3 3
60	Cylinder Base	31 500 33 180	60 800 60 750	14.8 16.4	21.8 19.9	127 134	2 2
36	Cylinder Base	32 590 32 260	60 800 60 500	14.2 15.2	17.7 22.3	124 128	2 2
24	Cylinder Base	34 900 33 650	60 730 60 650	10.0 15.3	15.8 20.1	136 128	3 2
16	Cylinder Base	34 900 33 880	60 730 60 700	10.0 11.4	15.8 15.7	136 135	3 3
12	Cylinder Base	35 340 33 530	66 150 60 830	12.7 16.3	14.5 21.4	133 135	2 2
10	Cylinder Base	35 180 37 500	65 720 58 430	19.9 10.3	25.9 15.2	128 138	3 3
6	Cylinder Base	35 580 37 640	65 020 63 920	13.7 12.6	16.5 18.3	136 132	3 3
3	Cylinder Base	36 000 35 660	64 370 60 670	10.5* 9.9	15.3 16.1	127 134	2 3

\*One test.

of material and had the same composition and the same heat treatment. Two or more tests were made on each pair of specimens after each heat treatment, the specimens being shifted between tests so as to bring the area in contact at different portions of the finished surface for successive tests. The composition and the heat treatment for the various specimens are given in Table 6, and the physical properties in Table 7.

Six rollers, all 6 in. in diameter, were used in Series E. They were made of hot-rolled steel, and there were two of each of three compositions, designated by specifications as S.A.E. 1020, 1035, and 1045. One roller of each pair was stress-relieved and the other hardened by heat treatment. The four rollers used in Series F were medium-grade steel castings; two were 6 in. and two 24 in. in diameter. One roller of each pair was stress-relieved and one was hardened by heat treatment. The roller used in Series H was a manganese-steel casting and was a segment of a cylinder having a diameter of 24 in. The rollers used in Series T were high-carbon tool steel. One was 6 in. in diameter and the other was a segment of a 24-in. cylinder. For both series H and T the specimens were first stress-relieved by heat treatment. After being tested in this condition the same blocks were hardened by heat treatment, refinished, and again tested.

The relation between the bearing value of the roller and the yield point of the material in tension\* is shown in Fig. 13.

The breaking down of a roller as the load increases does not occur abruptly, and there is no load at which there is a marked change in the behavior of the roller under continuous rolling. Also the term *bearing value* of a roller as used in this bulletin is not capable of a precise definition. Moreover, the results of the tests are not as consistent as could be desired. That the results of all the tests should be accurately connected by a simple law, therefore, is too much to be hoped for, and no curve showing the relation between the variables of Fig. 13 is offered; but the tests indicate that the bearing value of the rollers decreases rapidly with the yield point of the material. The individual tests represented are static tests and, because the rollers are small, the static tests gave a bearing value which is probably much less, as indicated by Fig. 10, than would have been obtained if the same specimens had been subjected to the rolling tests used by Holt and by Brown and Hartmann.

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\*The hardened manganese steel and high carbon tool steel do not have a well-defined yield point. A value of three-fourths of the ultimate strength has been used.

TABLE 6  
CHEMICAL COMPOSITION AND HEAT TREATMENT OF SPECIMENS; STATIC TESTS BY HEDEFINE

Series	Specimen	Material	Chemical Composition						Heat Treatment
			C	P	S	Si	Mn	Va	
D	All Specimens of Series	Medium-Grade Steel Casting (Annealed at foundry)	0.283	....	0.043	0.046	0.496	....	Held at 1300 deg. F. for four hours; cooled in furnace.
E	E-6-1	Structural Steel (S.A.E. 1020)	0.15 to 0.25	0.045	0.05	....	0.30 to 0.60	....	Held at 1300 deg. F. for four hours cooled in furnace.
	E-6-2	Structural Steel (S.A.E. 1035)	0.30 to 0.40	0.045	0.05	....	0.50 to 0.80	....	
	E-6-3	Structural Steel (S.A.E. 1045)	0.40 to 0.50	0.045	0.05	....	0.50 to 0.80	....	
	EE-6-1	Structural Steel (S.A.E. 1020)	0.15 to 0.25	0.045	0.05	....	0.30 to 0.60	....	
E	EE-6-2	Structural Steel (S.A.E. 1035)	0.30 to 0.40	0.045	0.05	....	0.50 to 0.80	....	Held at 1560 deg. F. for four hours; quenched in water; held at 900 deg. F. for three hours.
	EE-6-3	Structural Steel (S.A.E. 1045)	0.40 to 0.50	0.045	0.05	....	0.50 to 0.80	....	
	F-6 F-24	Medium-Grade Steel Casting	0.283	....	0.043	0.046	0.496	....	
	FF-6 FF-24	Medium-Grade Steel Casting	0.283	....	0.043	0.046	0.496	....	
H	H-24	"Hylastic" Steel Casting	0.35	0.02	0.03	0.40	1.45	....	Normalized at foundry.
H	HH-24	"Hylastic" Steel Casting	0.35	0.02	0.03	0.40	1.45	....	Held at 1500 deg. F. for three hours; quenched in oil; held at 700 deg. F. for three hours.
T	T-6 T-24	Carbon Tool Steel	0.95 to 1.05	0.02	0.03	0.15 to 0.25	0.20 to 0.30	0.20 to 0.25	Commercially annealed.
T	TT-24	Carbon Tool Steel	0.95 to 1.05	0.02	0.03	0.15 to 0.25	0.20 to 0.30	0.20 to 0.25	Held at 1500 deg. F. for three hours; quenched in water at 70 deg. F.; held at 700 deg. F. for three hours.



TABLE 7  
PHYSICAL PROPERTIES OF SPECIMENS; STATIC TESTS BY HEDEFINE

Series	Specimen	Location	Yield Pt. Strength lb. per sq. in.	Ultimate Strength lb. per sq. in.	Elong. in 2 in. per cent	Red. of Area per cent	Brinell Number	Rockwell Number	Scleroscope Number	No. of Tests Averaged
E	E-6-1	Cylinder	29 500	54 600	43.3	64.4	105	....	....	2
	E-6-1	Base	33 420	64 775	33.5	47.5	117	....	....	2
	E-6-2	Cylinder	31 100	67 925	35.0	51.8	125	....	....	2
	E-6-2	Base	32 355	68 775	29.8	42.0	117	....	....	2
	E-6-3	Cylinder	36 725	72 620	34.0	53.3	152	....	....	2
	E-6-3	Base	47 300	91 375	28.5	41.0	170	....	....	2
	EE-6-1	Cylinder	41 040	65 950	34.5	63.0	138	....	....	2
	EE-6-1	Base	46 725	80 200	22.0	35.1	151	....	....	2
	EE-6-2	Cylinder	56 850	94 675	23.3	49.0	172	....	....	2
	EE-6-2	Base	55 885	87 875	23.8	45.7	171	....	....	2
	EE-6-3	Cylinder	60 350	102 770	22.0	48.3	225	....	....	2
	EE-6-3	Base	76 950	121 900	17.3	41.7	259	....	....	2
F	F-6	Cylinder	35 580	65 020	13.7	16.5	136	....	....	3
	F-6	Base	37 640	63 920	12.6	18.3	132	....	....	3
	F-24	Cylinder	34 900	60 730	10.0	15.8	136	....	....	3
	F-24	Base	33 650	60 650	15.3	20.1	128	....	....	2
	FF-6	Cylinder	49 150	79 550	6.8	8.6	190	....	....	2
	FF-6	Base	58 975	83 075	5.8	10.0	248	....	....	2
	FF-24	Cylinder	55 260	79 700	4.5	6.7	275	....	....	2
	FF-24	Base	56 502	83 950	8.3	12.7	204	....	....	2
	H-24	Cylinder	59 580	104 500	18.0	31.1	203	....	....	3
	H-24	Base	59 580	104 500	18.0	31.1	196	....	....	3
	HH-24	Cylinder	.....	135 550	.....	.....	338	40.3†	46.5†	2
	HH-24	Base	.....	135 550	.....	.....	344	40.3†	36.9	2
T	T-6	Cylinder	45 600*	82 150*	34.0*	57.0*	161	....	....	..
	T-6	Base	41 450*	82 400*	23.5*	34.3*	161	....	....	..
	T-24	Cylinder	41 450*	82 400*	23.5*	34.3*	161	....	....	..
	T-24	Base	41 450*	82 400*	23.5*	34.3*	161	....	....	..
	TT-6	Cylinder	.....	212 200*	.....	.....	713	47.8†	47.2†	..
	TT-6	Base	.....	200 800*	.....	.....	569	42.7	48.4	..
	TT-24	Cylinder	.....	200 800*	.....	.....	652	46.8	66.5	..
	TT-24	Base	.....	200 800*	.....	.....	569	42.7	48.4	..
	P-4	Cylinder	35 110	61 115	37.4	55.4	122	....	....	2
	P-4	Base	33 400	53 020	40.7	59.6	104	....	....	3

\*From one test only

†Taken on control specimens and not on test specimen.

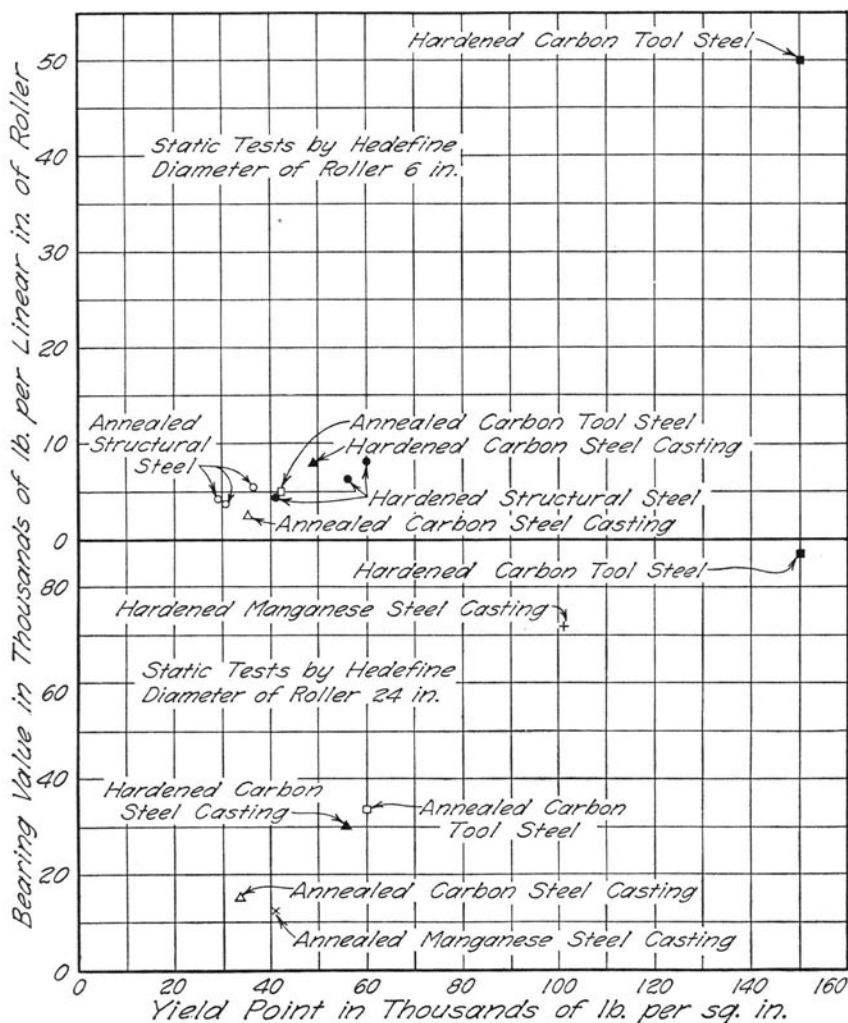


FIG. 13. RELATION BETWEEN STRENGTH OF MATERIAL AND BEARING VALUE OF ROLLER

8. *Static Tests by Brown and Hartmann.*—Static tests were made by Brown and Hartmann to determine the effect of variations in the physical properties of the base upon its bearing value when loaded with a hard roller. The rollers were made of medium-grade carbon steel castings hardened by heat treatment. The average Brinell Number for the rollers was 328. The yield-point strength of the bases varied from 26 900 lb. per sq. in. to 47 000 lb. per sq. in. Tests were

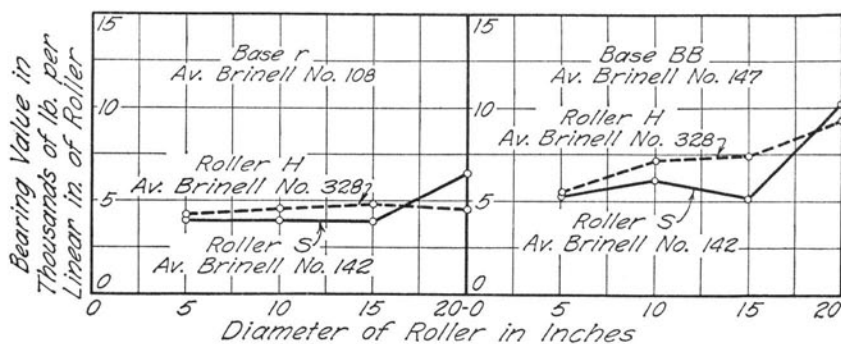


FIG. 14. COMPARISON OF BEARING VALUES OF BASES UNDER MEDIUM AND HARD ROLLERS

made with rollers having diameters of 5 in., 10 in., 15 in., and 20 in. The results of the tests are shown in Fig. 11. These tests apparently indicate that the strength of a roller bearing upon a base depends upon the strength of the weaker material. This is further supported by the tests reported in Fig. 14, in which each of two bases was tested under rollers of different strengths.

In the rolling tests reported by Brown and Hartmann, the top of the roller in contact with a very hard plate began to flow at a lower load than the bottom of the roller in contact with a base made of material of the same strength as that used for the roller. This relation existed throughout the entire series, and was too pronounced to be considered erratic or accidental.

Therefore it seems that, for a roller and base of different materials, the static tests indicate that the strength of the pair is determined by the strength of the weaker material, whereas the rolling tests indicate that the strength of the weaker member is reduced because of the greater strength of the member with which it is in contact.

#### IV. SUMMARY OF RESULTS

9. *Summary of Results.*—The bearing value of a roller, as defined in this bulletin, is the load producing a plastic flow of 0.001 inch per inch when the roller is rolled 1000 strokes at the given load. This criterion has been adopted because the curve showing the relation between the load and the plastic flow does not contain a "break," and it seemed desirable to adopt a criterion for determining the bearing value that would not involve the "personal equation."

Although the criterion here adopted appears more or less arbitrary, it does determine as the bearing value a load such that increases beyond this load are accompanied by a rapid increase in the rate of plastic flow. It is realized, however, that the values for the bearing value obtained on the basis of this criterion are relative rather than absolute. If a different criterion had been used a different series of bearing values would have been obtained. This factor should be taken into consideration when the results presented are made the basis of a design formula.

The bearing values of rollers of various diameters made of a medium-grade carbon steel casting are shown in Fig. 4; the bearing values of rollers made of various kinds of steel, and with diameters of 6 inches and 24 inches, respectively, are shown in Fig. 13.

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